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RESEARCH DEPARTMENT

A TRANSMITTING AERIAL FOR PROPAGATION MEASUREMENTS IN BAND V (610-960 Mc/s)

Report No. E-068

(1959/13)

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

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A TRANSMITTING AERIAL FOR PROPAGATION MEASUREMENTS IN BAND V (610-960 Mc/s)

SUMMARY

A horizontally-polarized low-power transmitting aerial designed for propagation measurements in Band V (610-960 Mc/s) is described. The aerial was originally designed for operation in a narrow frequency band centred on 900 Mc/s. Later the frequency allocation was changed to 774 Mc/s, so that the aerial had to be modified. The measured results include radiation patterns in the horizontal and principal vertical planes, and admittance characteristics.

1. INTRODUCTION

The aerial described was developed for propagation tests employing horizontal polarization in Band V (610-960 Mc/s). It was required to radiate from a fixed site towards a number of receiving stations in approximately the same direction, but at different distances from the transmitting station; the horizontal radiation pattern was required to be relatively wide in order not to restrict the selection of receiving sites. The following specification was therefore prepared:-

(1) The power gain to be not less than 15 dB relative to a $\lambda/2$ dipole.

(2) The beamwidth to half-power points in the horizontal plane to be approximately $\pm 20^\circ$; this implies that the beamwidth in the vertical plane must not exceed approximately $\pm 6^\circ$ in order to satisfy the power gain requirement.

(3) The standing-wave ratio (s.w.r.) to be better than 0·9 at the frequency specified (when connected to 70 Ω feeder).

(4) The aerial to be capable of radiating the output of a transmitter which can be modulated either with square-waves having a mean power of 50 watts, or 0·5 μs pulses having a p.r.f. of 1000 c/s and a peak power of 10 kW.

(5) The aerial to withstand rigorous climatic conditions (including snow and ice formation) for long periods without attention, and to be such that its performance is unaffected by the supporting mast.

An aerial was made to meet this specification at 900 Mc/s. The frequency allocation was subsequently changed to 774 Mc/s and it was decided to modify the aerial then existing without changing its overall dimensions. This meant that parts (1) and (2) of the original specification could not be satisfied because of the reduced dimensions of the aerial in terms of the wavelength. The power gain requirement was therefore relaxed to 13·5 dB relative to a $\lambda/2$ dipole and the beamwidths (to half-power points) increased to $\pm 24^\circ$ and $\pm 8^\circ$ for the horizontal and vertical planes, respectively. The remainder of the specification was unchanged.

2. THE DESIGN OF THE AERIAL

2.1. Preliminary Considerations

The required directivity could have been achieved with an array of Yagi aerials but this arrangement was not used because of difficulties of feeding and de-icing. It was decided instead to use an aerial incorporating a reflecting surface, with a polythene cover over the aperture to protect it from the weather. A corner reflector was eventually adopted. Parabolic and cylindrical reflectors were considered, but they would have been more difficult to manufacture and appeared to offer no great advantages.

It is usual for the dipoles exciting a corner reflector to be oriented with their axes parallel to the axis of the reflector apex.[1] Since horizontal polarization was specified, a corner reflector excited by conventional electric dipoles would therefore have to be mounted with its apex axis horizontal; with this arrangement, however, the required vertical directivity could not be conveniently achieved. It was therefore decided to mount the reflector with its apex axis vertical and to excite it with the equivalent of an array of magnetic dipoles, a slotted cylinder. With this arrangement it was found experimentally that the requirements could be satisfied by a corner reflector 4·5λ high and 1·18λ wide.

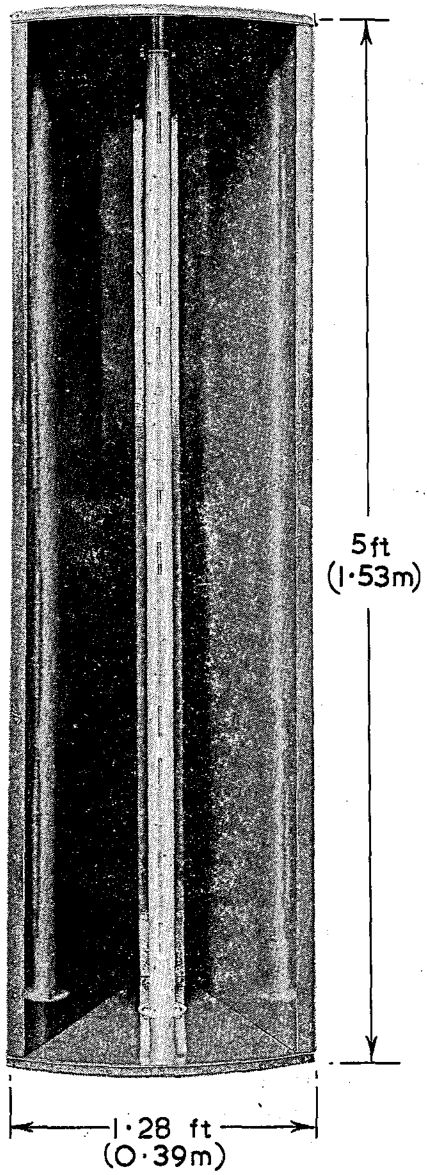

Fig. 1 - Aerial with cover removed

2.2. Description of the Aerial

A photograph of the aerial with its polythene cover removed is shown in Fig. 1. It consists of a 45° corner reflector with closed ends which support the exciting element. To ease the problem of mounting the aerial on a mast the apex of the corner is truncated; this has been found[1] to have a negligible effect on the radiation pattern.

For maximum power gain the slotted cylinder should extend over the full length of the corner reflector and the voltage across the slot should be constant in amplitude and of the same phase along its length. A good approximation to this condition may be obtained by dividing the slot into a number of sections driven in phase at their mid-points.

A slotted cylinder can be considered[2] as a balanced transmission line loaded by distributed shunt inductance. It behaves in a manner similar to a waveguide, with a phase velocity greater than that of light at frequencies above a critical (or "cut-off") frequency. The effect of the distributed shunt inductance may be modified and controlled by the addition of capacity plates placed along the length of the slot. In this way a centre-driven slot of any length may be made to have an electrical length corresponding to half-wave resonance. In practice the phase velocity cannot conveniently be made greater than twice the velocity of light because the change of velocity with frequency is then so rapid that the bandwidth of the aerial is unduly restricted. The slots used in the aerial are one wavelength long, corresponding to a phase velocity twice that of light; four such slots are used to excite the reflector. Capacity plates are fitted only over a length of $0{\cdot}31\lambda$ on each side of the driving points, rather than along the entire length. This arrangement may be considered analogous to a biconical dipole and has the desirable property of increasing the bandwidth.

Fig. 2 shows the general arrangement of the slotted cylinder. It contains a tube which is split at its mid-point and which itself contains a coaxial cable, shorn of its outer conductor. The generator is effectively connected across the gap at the mid-point of the inner conductor, through a series compensating stub to be described later. Co-phased slot voltages are established by tapping probes on to the tube at intervals of one wavelength, the probes being connected to opposite sides of the slots in the upper and lower halves of the aerial.

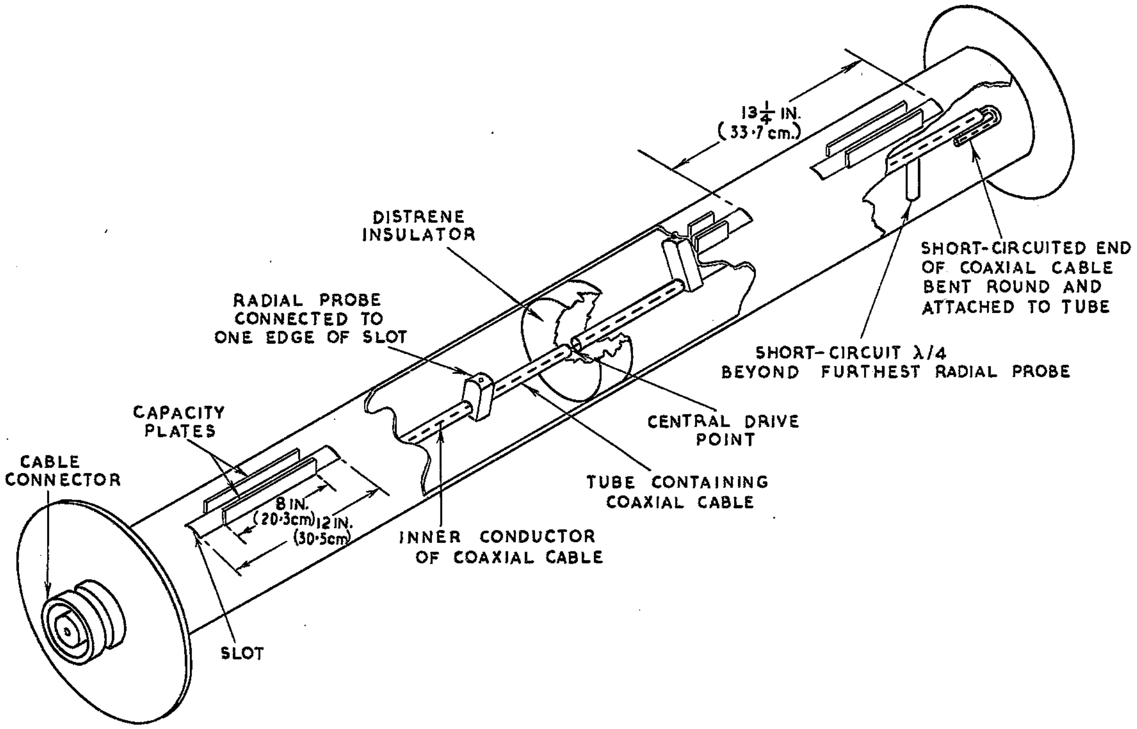
13¼ IN.
(33·7 cm.)
DISTRENE INSULATOR
SHORT-CIRCUITED END OF COAXIAL CABLE BENT ROUND AND ATTACHED TO TUBE
RADIAL PROBE CONNECTED TO ONE EDGE OF SLOT
SHORT-CIRCUIT λ/4 BEYOND FURTHEST RADIAL PROBE
CAPACITY PLATES
CENTRAL DRIVE POINT
CABLE CONNECTOR
TUBE CONTAINING COAXIAL CABLE
8 IN.
(20·3cm)
12 IN.
(30·5cm)
INNER CONDUCTOR OF COAXIAL CABLE
SLOT

Fig. 2 - The slotted cylinder

The tube is supported at intervals along its length by distrene spacers and its ends are terminated by short-circuits one quarter of a wavelength beyond the outermost probes. The cable inside the tube is connected to a Telconnector socket at the lower end of the cylinder. Its inner conductor is not connected directly to the farther half of the tube but is continued across the break to the end of the cylinder to form a series-impedance compensating stub. This arrangement has the advantage that no soldered electrical connection is required at the mid-point of the slotted cylinder. The end of the compensating stub protrudes from the end of the cylinder, where it is readily accessible, and at this point it is complete with its original outer braiding. It is terminated in a short-circuit, the length being chosen to give the required compensation and a good admittance match. Additional admittance correction is achieved by adding parallel capacitors on the inner conductor on each side of the centre spacer, in the form of brass cylinders. The equivalent circuit is shown in Fig. 3.

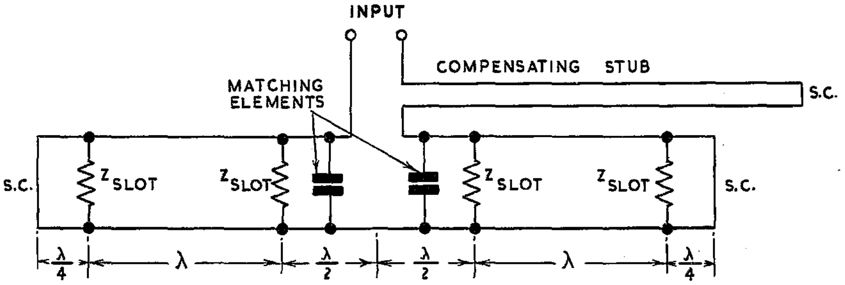

Fig. 3 - Equivalent circuit of the feeder system

The coaxial cable used is Telcon type PT1M (UR No. 32). This limits the mean power-handling capacity of the aerial to 70 watts at 900 Mc/s. A simple modification would enable Uniradio No. 1 to be used; the mean power rating could then be increased to 230 watts.

A sheet of black polythene, 1/8 in. (3 mm) thick, is secured to the front of the corner reflector to protect the slotted cylinder from the weather. The slotted cylinder and the metal components of the feeder system are silver plated. The corner reflector itself is made of a weather-resisting aluminium alloy.

3. RADIATION PATTERNS AND GAIN

3.1. Horizontal Radiation Pattern

Preliminary horizontal radiation pattern (h.r.p.) measurements were made using a single slot (cylinder diameter 0·14 λ) in an open-ended corner reflector. Experiments were carried out to determine:-

(1) The required angle between the sides of the reflector.

(2) The side dimensions.

(3) A suitable range of spacings between the slotted cylinder and the apex of the reflector; the reflector was not truncated at this stage.

These parameters were found to be interdependent to some extent, but a set of values was chosen for which the dimensions were not critical, so that production tolerances would be eased.

Measurements of h.r.p. were made with the slot facing the apex and also in the opposite direction. As a result of these preliminary tests it was decided to use a 45° corner reflector with sides 1·0λ wide and to mount the cylinder with its slot facing outwards and with its axis between 0·4λ and 0·6λ from the apex. The h.r.p. did not change appreciably over this range, so that the final position of the cylinder was not decided until admittance measurements had been made. The h.r.p. ultimately achieved at 900 Mc/s is shown in Fig. 4.

3.2. Vertical Radiation Pattern

The vertical radiation pattern (v.r.p.) in the forward direction is very similar to that of an array of collinear half-wave dipoles having the same spacing as the slots. It was found that the original specification could be satisfied by four slots with their centres spaced 1·0λ apart. Fig. 5 shows the v.r.p. measured at 900 Mc/s; for comparison the pattern for four collinear half-wave dipoles with the same spacing is also shown.

The addition of metal plates to the top and bottom of the reflector was found to have only a small effect on the v.r.p. This was fortunate because these plates provide a convenient mechanical support for the slotted cylinder and also assist in protecting the aerial from the weather.

3.3. Power Gain

It would be very laborious to compute the power gain of the aerial exactly, because radiation patterns would have to be measured in a large number of planes. The following method was therefore used. The r.m.s. value of the h.r.p. was computed and the power gain which the aerial would have if excited by one slot was taken to be the ratio of the maximum field to the r.m.s. field. To this was added the power gain of four collinear half-wave dipoles having the same spacing as the slots. This gives the intrinsic gain of the aerial; the net gain is slightly smaller on account of loss in the coaxial cable inside the tube.

The net gain was estimated as 15·1 dB; this was made up as follows:-

Estimated gain of aerial if excited by one slot, relative to a $\lambda/2$ dipole	9·3 dB
Theoretical gain of 4 collinear dipoles spaced 1·0λ, relative to a $\lambda/2$ dipole	6·5 dB
Intrinsic gain, relative to a $\lambda/2$ dipole	15·8 dB
Loss in coaxial cable	0·7 dB
Net gain, relative to a $\lambda/2$ dipole	15·1 dB

The power gain of the 900 Mc/s aerial was not measured. However, a similar estimate of the gain was made for the modified aerial working on 774 Mc/s and this agreed within 0·4 dB with the measured value.

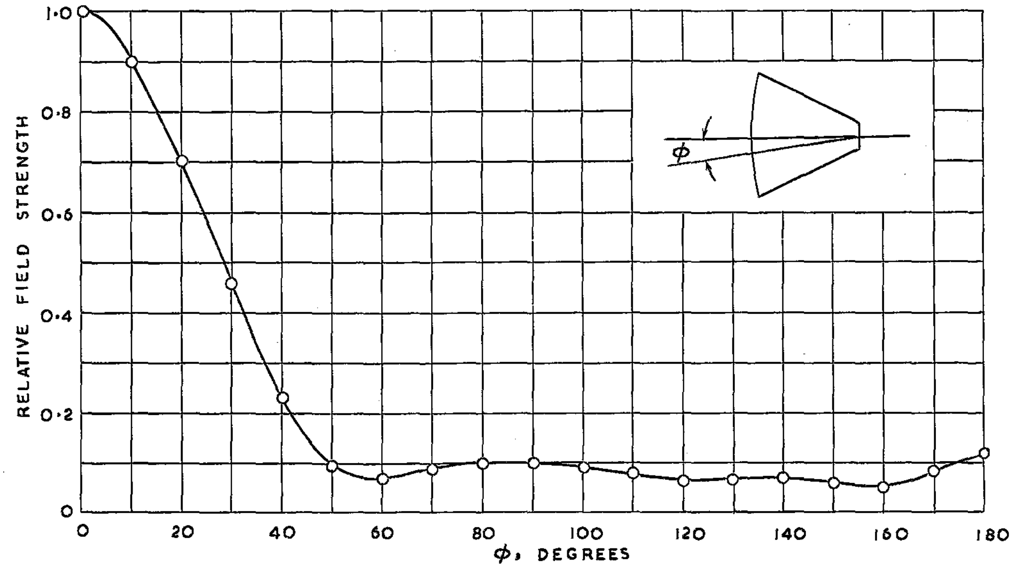

Fig. 4 - Horizontal radiation pattern of the 900 Mc/s aerial

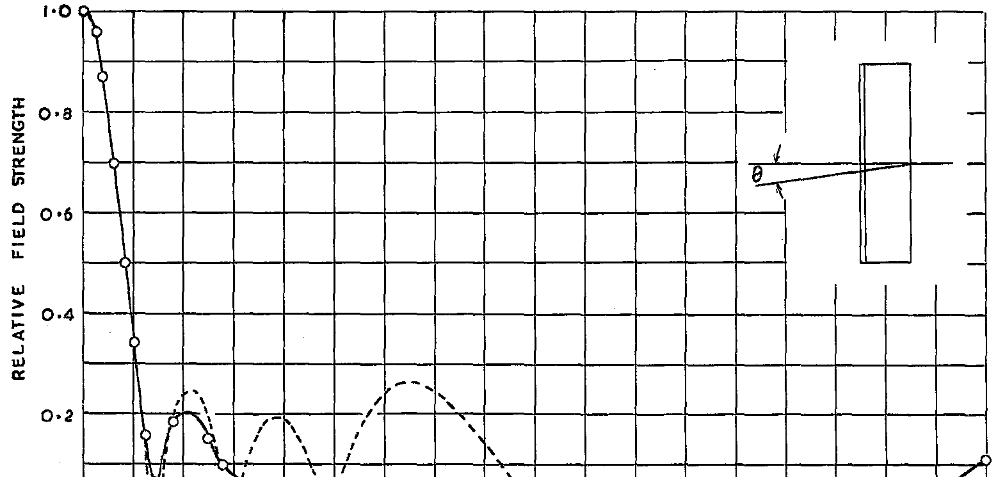

Fig. 5 - Vertical radiation pattern of the 900 Mc/s aerial

—o—Measured v.r.p.

----Theoretical v.r.p. of four collinear half-wave dipoles spaced 1·0λ (0<θ<90°)

4. ADMITTANCE

The parameters available for admittance matching are (a) variations in the distance of the slotted cylinder from the apex of the corner reflector, (b) changes of slot length, (c) addition of distributed capacitance between the slot faces, (d) addition of lumped capacitance to the inner tube of the slotted cylinder on each side of the centre spacer and (e) variation in the length of the series compensating stub.

In general the presence of the corner reflector modifies the free-space admittance of the slotted cylinder. The change in admittance depends on the distance of the slotted cylinder from the apex of the reflector, but at one particular distance it was found to be negligible; this spacing was adopted because it also gave the maximum bandwidth. To increase the bandwidth still further it is desirable to introduce compensation over a limited range by adding a series reactance having an equal and opposite slope with frequency. This can be conveniently carried out by a stub either in series with each individual slot or at the centre of the system, since the feed point is approximately $\lambda/2$ from the inner slots. In the latter case one stub will compensate all four slots simultaneously; this arrangement was therefore adopted.

For admittance measurements the aerial was connected to a General Radio admittance meter modified for use with 70 Ω cable. The measuring system was calibrated by the use of a well-matched termination and the subsequent results were normalized to this value. The electrical length of the cable and its loss were determined in a separate experiment. The s.w.r. could be adjusted to almost unity by varying the length of the series stub and by fitting solid brass cylinders of suitable length and diameter on the tube near the driving point.

The addition of the front polythene cover was found to increase the reflection coefficient of a well-matched aerial by 4%. This figure agrees well with the theoretical reflection coefficient (3%) for a plane wave normally incident on an infinite polythene sheet of the same thickness. Fig. 6 shows the input admittance of the 900 Mc/s aerial.

5. MODIFICATION OF THE AERIAL TO WORK AT A LOWER FREQUENCY

When the frequency allocation was changed to 774 Mc/s it was decided to modify the existing aerial. No change was made in leading dimensions and consequently the spacing between the drive points of the slots was reduced to 0·86λ. This meant that, with the same distribution feeders, the slots would not have been driven in phase and a poor radiation pattern would have resulted. The tubes between the two slots in each half of the aerial were therefore loaded with distrene, to reduce the velocity of propagation and thus to re-establish a co-phased voltage distribution.

To match the aerial at the new frequency it was necessary to introduce distrene between the capacity plates of the slots; the distance between the slotted cylinder and the apex of the reflector also had to be changed. The solid brass cylinders on the inner conductor were dispensed with and the aerial was matched by varying the length of the centre spacer at the drive point and the length of the series compensating stub.

The radiation patterns and admittance of the modified aerial are shown in Figs. 7, 8 and 9. The power gain was estimated by the method described in Section 3.3 to be 13·8 dB. It was also measured directly by comparison with a $\lambda/2$ dipole; the measured value was 13·4 dB.

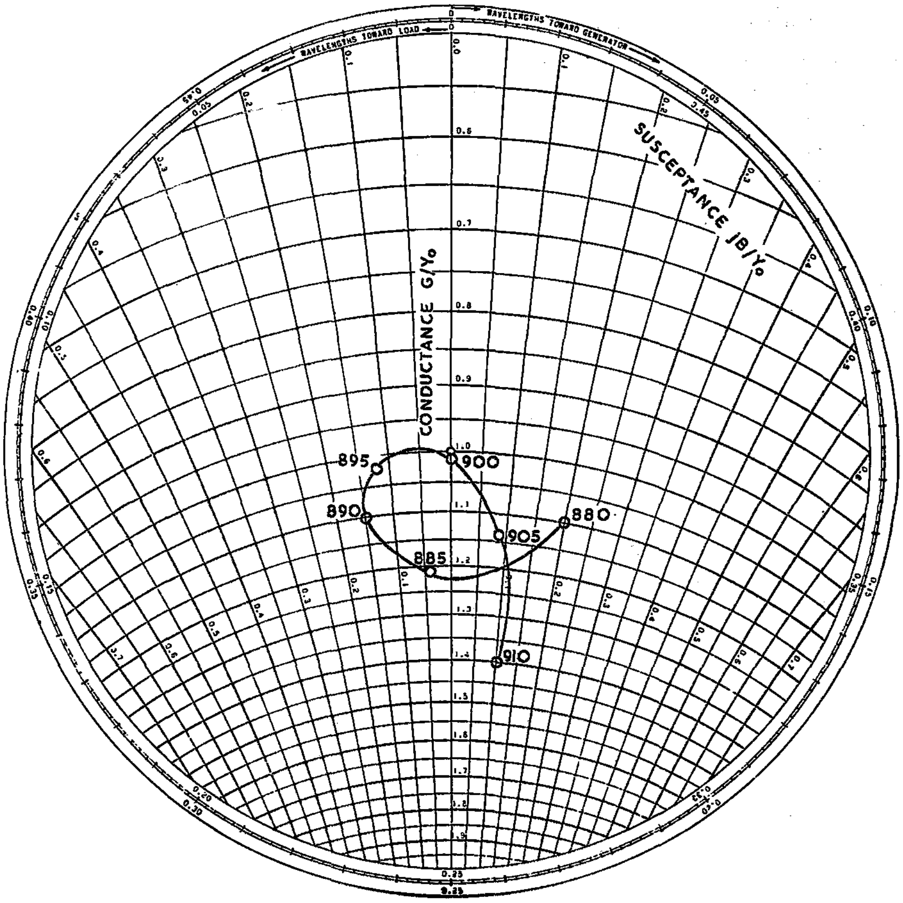

Fig. 6 - Input admittance of the 900 Mc/s aerial
Figures against the points indicate frequencies in Mc/s
Admittance normalized to 14·0 mmhos

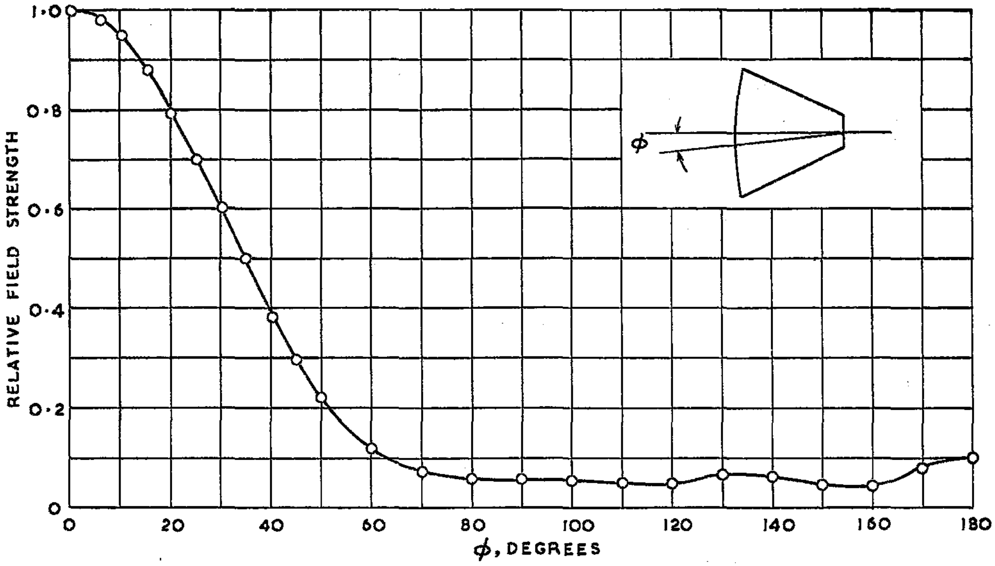

Fig. 7 - Horizontal radiation pattern of the 774 Mc/s aerial

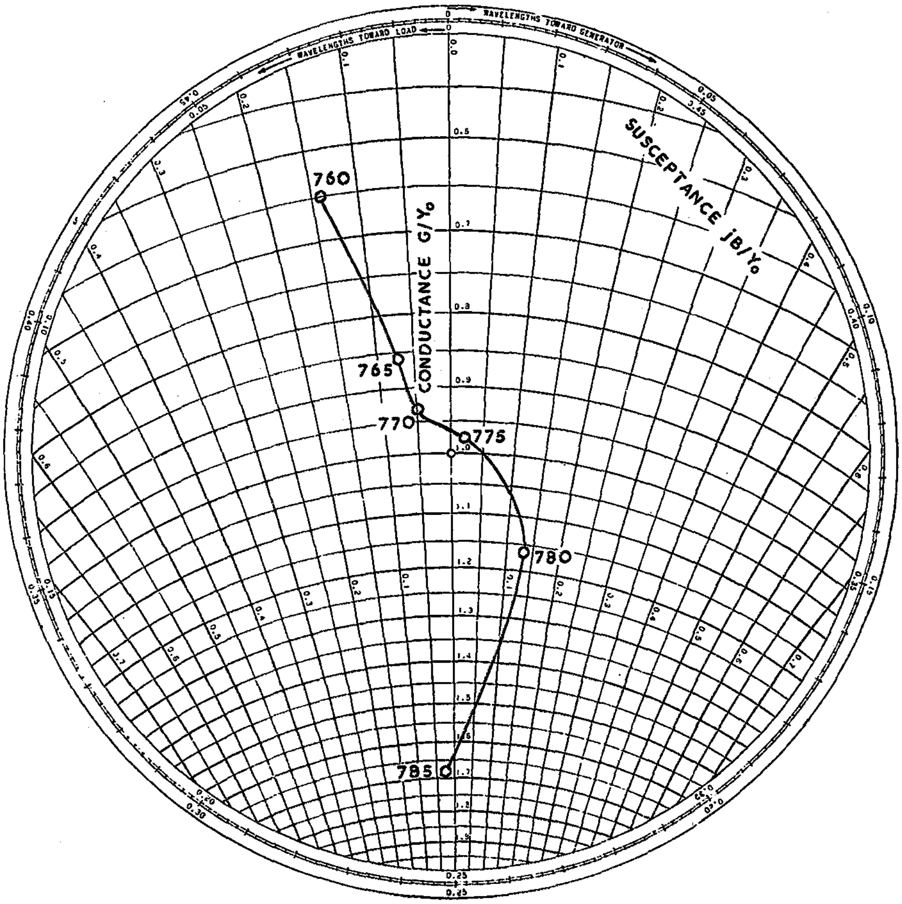

Fig. 8 - Input admittance of the 774 Mc/s aerial
Figures against the points indicate frequencies in Mc/s
Admittance normalized to 14·0 mmhos

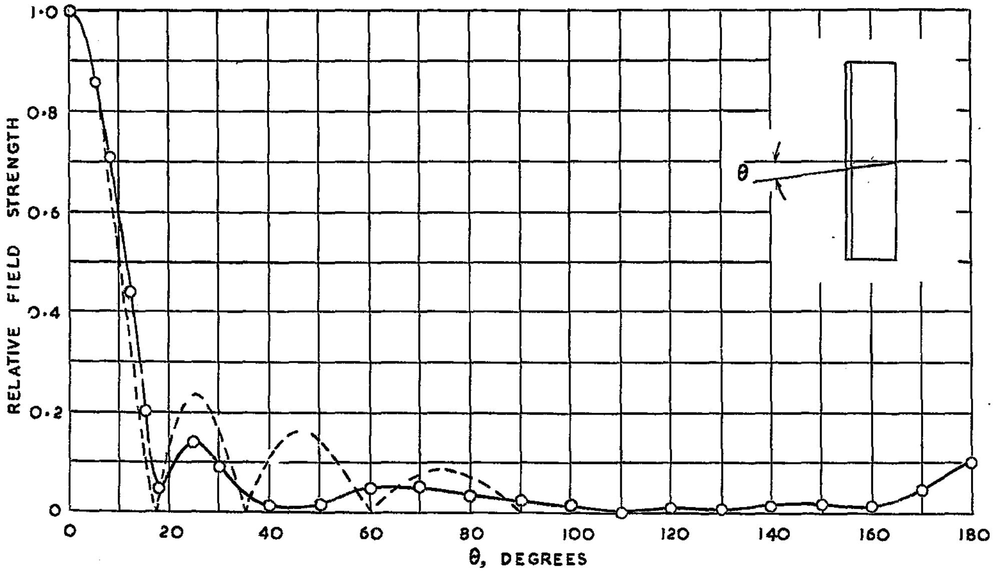

Fig. 9 - Vertical radiation pattern of the 774 Mc/s aerial

-o- Measured v.r.p.

--- Theoretical v.r.p. of four collinear half-wave dipoles spaced 0·86λ ($0<\theta<90^\circ$)

6. CONCLUSIONS

The measured performance of the aerial shows that the use of an array of slots as the exciting element for a corner reflector leads to efficient use of the reflector aperture. The aerial is intended for use with a transmitter which can be modulated either with square-waves having a mean power of 50 watts, or 0·5 μs pulses having a p.r.f. of 1000 c/s and a peak power of 10 kW; the power handling capacity of the aerial is sufficient for either requirement. Its bandwidth is adequate for the pulse condition.

It has been shown that the aerial can be matched at any frequency within a frequency range of 1·16 : 1 by making simple modifications to the slot loading and feeder system. There seems to be no reason why this range should not be extended, but an upper limit of 1·5 : 1 would be set by the dielectric constant of the distrene which is used to reduce the phase velocity inside the cylinder.

7. ACKNOWLEDGMENT

Mr. G.B. Collins designed and carried out the modifications required when the frequency was changed from 900 Mc/s to 774 Mc/s.

8. REFERENCES

1. Moullin, E.B., "Radio Aerials", Clarendon Press, 1949.

2. Beam, R.E., "Impedance and Radiation Characteristics of Slotted Cylinder Antennas", Proceedings of the National Electronics Conference, 1949.

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